

Simulations of Cosmic Structure Formation on the Harvard-CfA Beowulf Clusters

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Cosmological N -body simulations

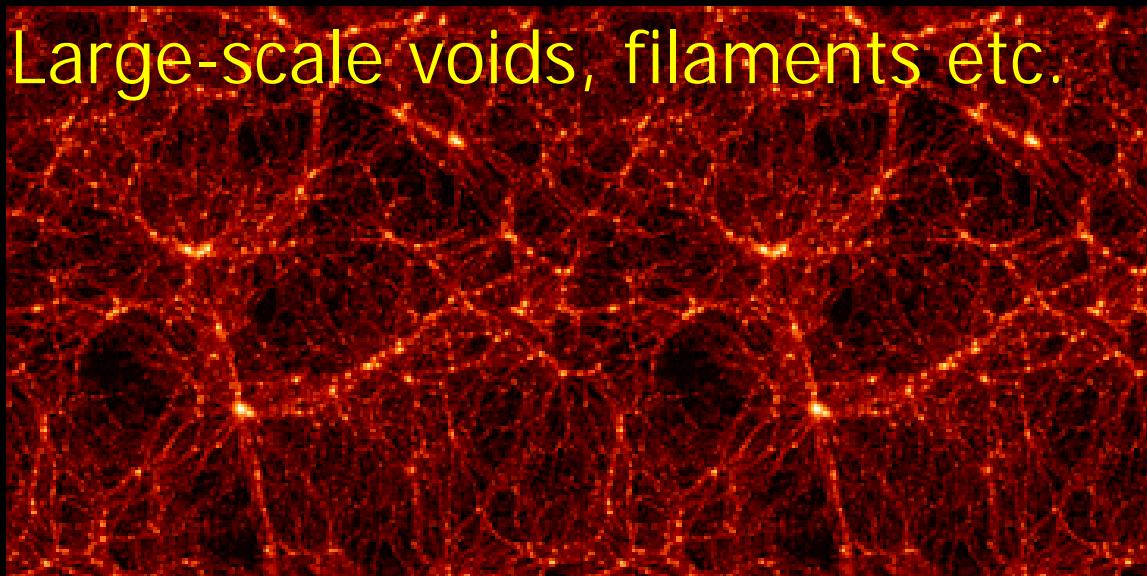
Galaxies



Galaxy clusters



Large-scale voids, filaments etc.



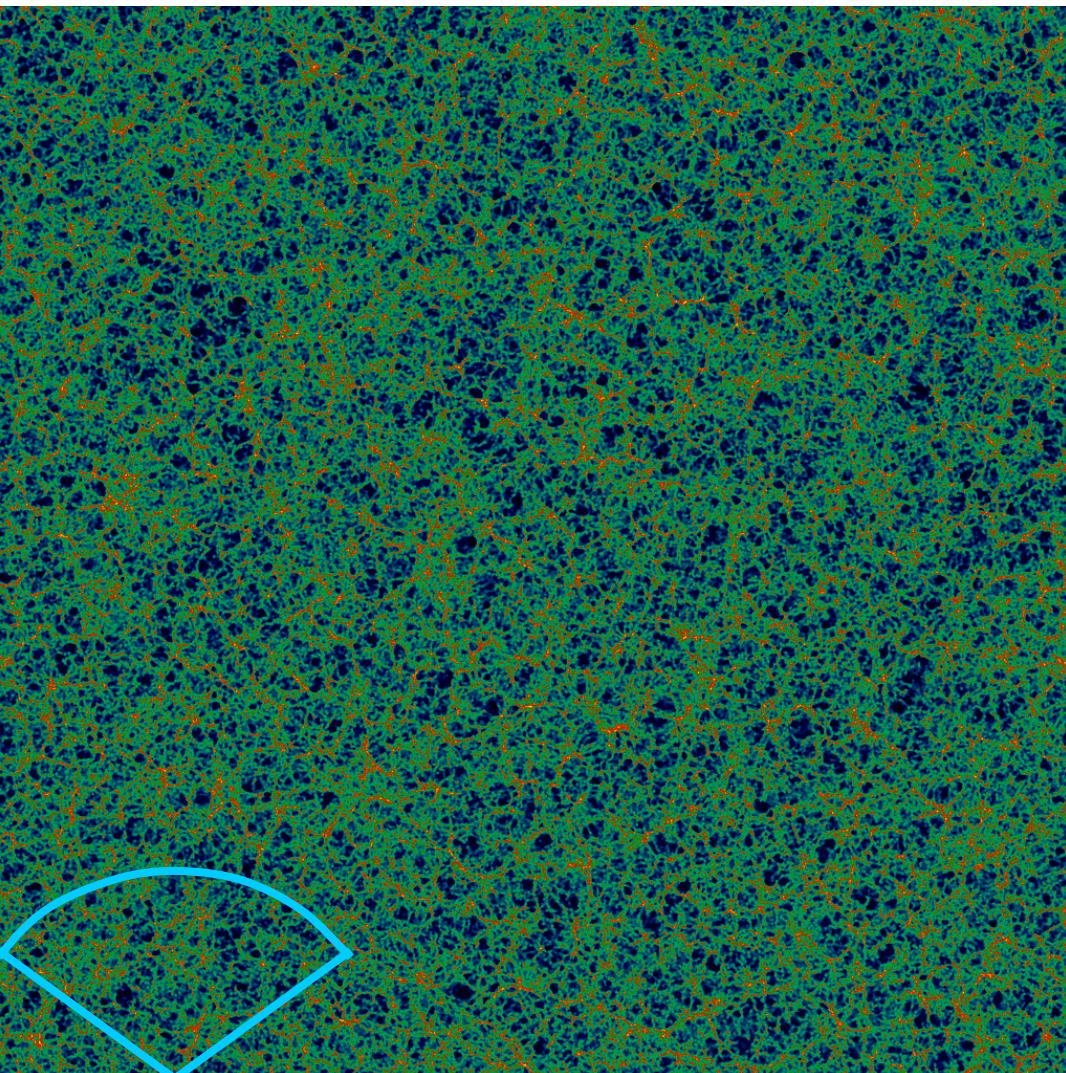
Nightmare of “large N ”

When simulating:

- Galaxies : $N \sim 10^5 - 10^6$ particles
- Galaxy clusters : $N \sim 10^6 - 10^7$
- Large-scale structure formation
 $N \sim 1,000,000,000$

The Hubble Volume Simulations

3000 Mpc/h



Standard LCDM model

1,000,000,000 CDM particles

Simulation box 3Gpc on a side

1 million rich galaxy clusters

512 cpu on Garching T3E

1998/8 - 1999/1

32 GB per snapshot

Parallel architectures

Cray T3E

SGI Origin 2000

Fujitsu VPP

Linux clusters*



100 – 1000 cpus

More than 100GB RAM
(distributed memory)

~ 1 TB output data

At least 7 words per particle/mass element,
plus typically 5-10 more words per gas particle;element.

CfA Beowulf clusters



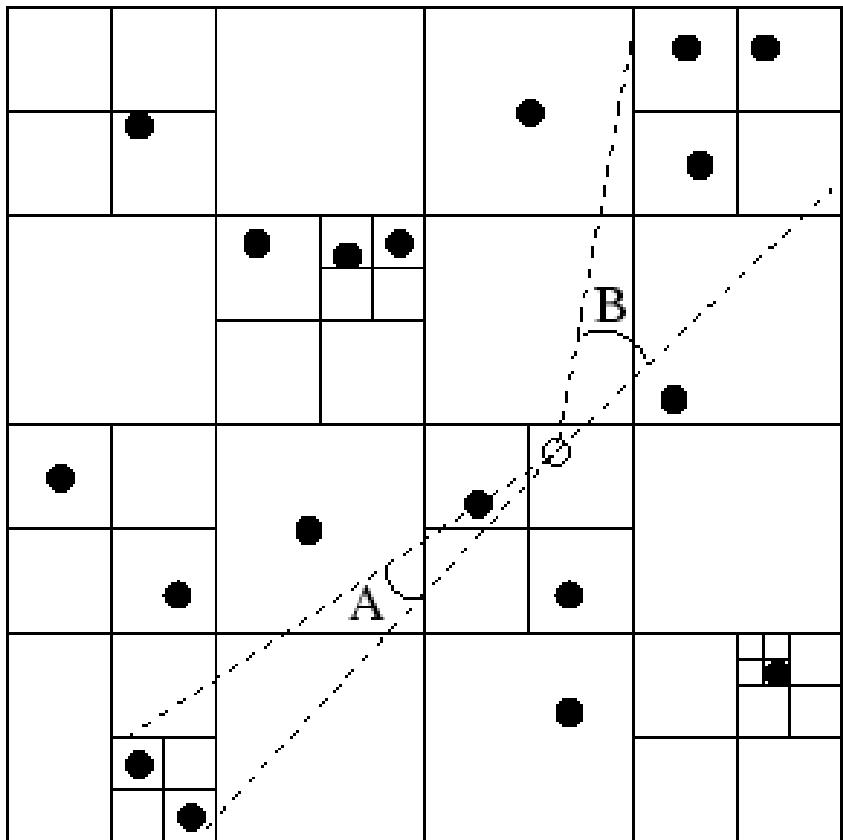
Linux clusters dedicated to astrophysical problems.
Primarily for N -body/hydro - simulations.

128 pentium III (64 nodes with 0.5/1 GB RAM per node)

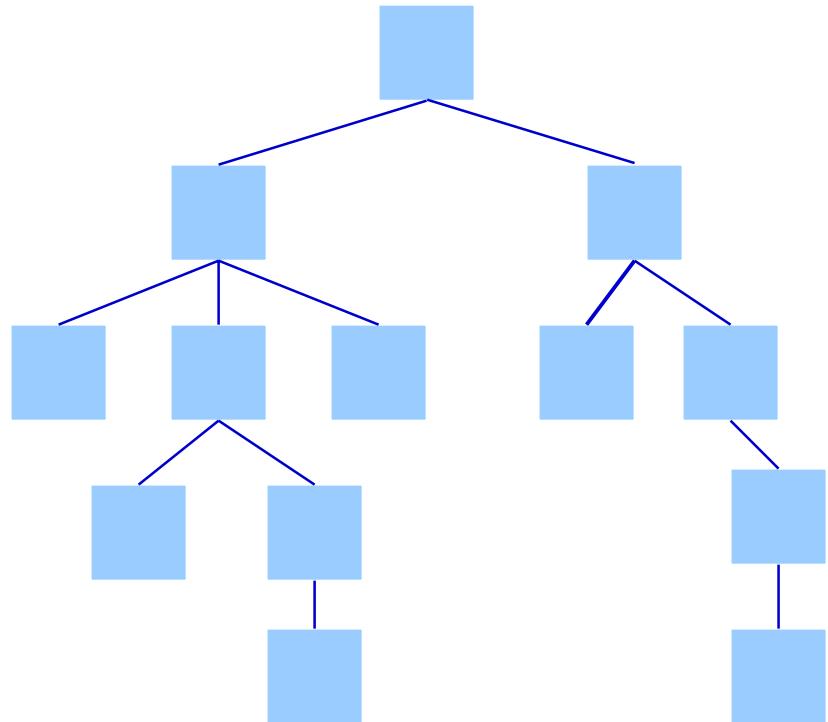
264 AMD Athlon (132 nodes with 1GB RAM per node)

Parallel N-body solver GADGET (Springel, Yoshida, White)
written in C/MPI.

Tree algorithm

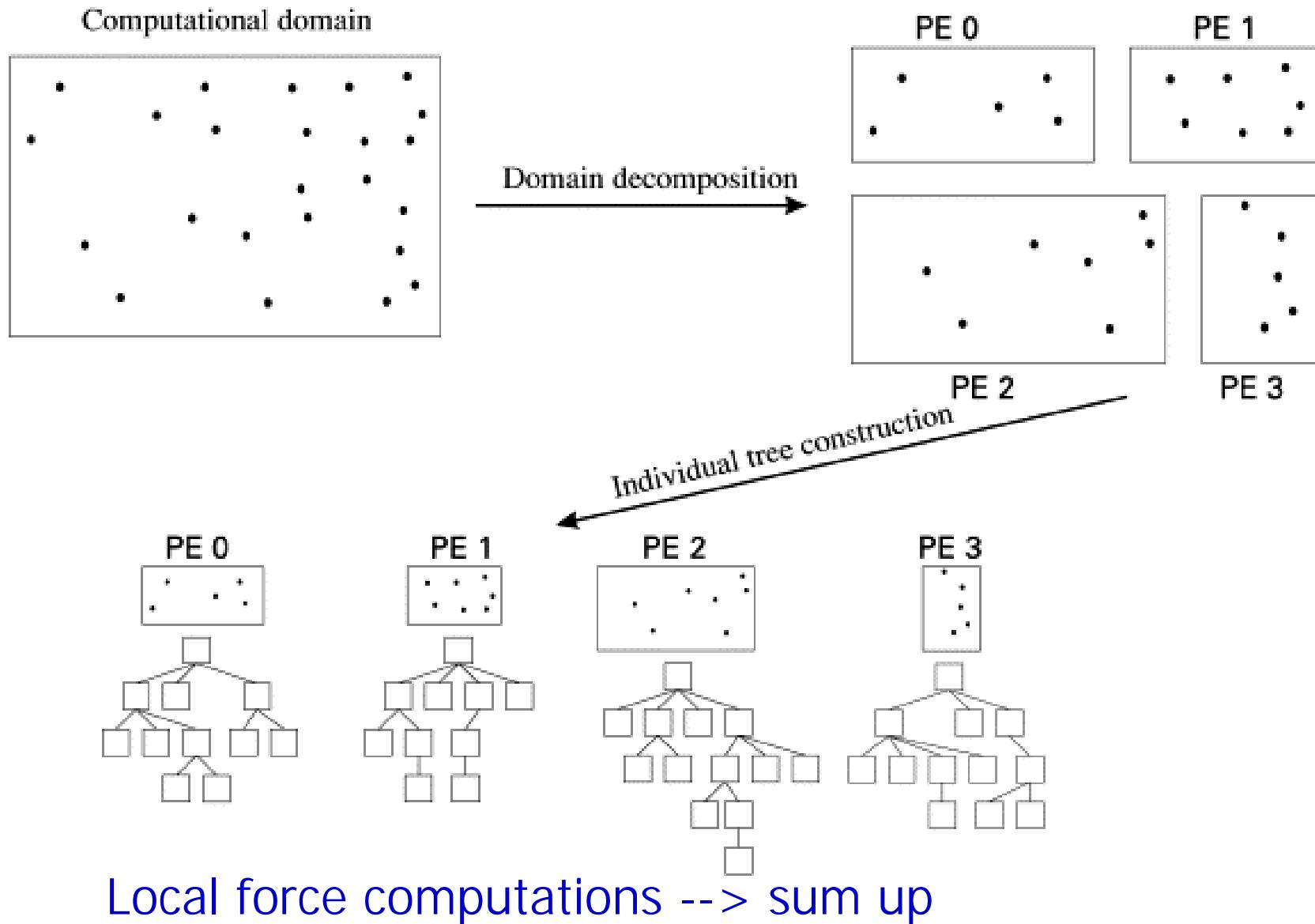


"Tree" data structure



N particles on a hierarchically decomposed rectangular grid

Tree algorithm on parallel computers



Performance and code optimization

1 million particles N -body/Hydro simulation
on 8 processors

650 MHz Pentium III vs 1.4GHz Athlon

| | speed up | |
|---------------|----------|--------|
| Total | 1.5 | |
| Gravity | 1.9 | (55 %) |
| SPH | 1.0 | (25 %) |
| Timestep | 4.3 | (1 %) |
| Communication | 1.65 | (10 %) |

Optimal cache usage

Accessing a contiguous block of RAM,
rather than hopping.

A factor of ~2.5 better performance expected.

Future plan

- Large ($N > 10^8$) simulations
- Machine specific optimization
 - Algorithm
 - Technical issues
- Performance tests on various architectures